Study of Z boson events in the decay to a tau lepton pair in the semileptonic channels with the CMS experiment at 13 TeV
Outline

> Introduction

> Results of $H(\tau\tau)$ in Run1

> Moving to Run 2 with the $Z(\tau\tau)$ standard candle

> Description of the analysis

> Topology

> Tau reconstruction

> Backgrounds

> Event Selection

> Corrections to MC

> Results

$H(\tau\tau)$ candidate event recorded by CMS in the 8 TeV run
Results after the LHC Run 1

> Motivation for \( H(\tau\tau) \) search

Detail study of **Yukawa couplings** - decay in two tau leptons is the most promising to measure the Higgs boson direct coupling to leptons and to fermions

Crucial test of electroweak symmetry breaking mechanism and probe of new physics

> With the LHC data taking in 2011-2012 a **5\( \sigma \)** evidence of \( H(\tau\tau) \) decays reached only combining **ATLAS and CMS** data.

> But the second LHC run has just started…
Beginning of the LHC Run 2

- Increase of the center-of-mass energy
  From 8 to 13 TeV, expected increase in the Higgs production cross section of a factor ~2

- First of all, we must make sure that we understand the physics observables, backgrounds, tau reconstruction, ...

- We can exploit the Z boson decays to a tau pair
  Well known electroweak process, with the same final state and the same mass scale of ~100 GeV
  Moreover, it is the main background for the $H(\tau\tau)$ search

Before searching for $H(\tau\tau)$ we are looking to $Z(\tau\tau)$ decays
Event topology

The **tau lepton** (1.777 GeV) decays to hadrons or to leptons ($e, \mu$) and neutrinos.

Two taus in the final state, I will focus on semileptonic channels

**Electrons and muons** are well reconstructed with the CMS detector

Experimental signature for neutrino is **missing energy** in the transverse plane
Hadronic tau reconstruction

The visible decay products of a $\tau_h$ are

> **Charged hadrons**
  > Jets anti-$k_T$ (R=0.5)

> **Neutral hadrons**
  > Two photons from the $\pi^0$, eventually convert to $e^+e^-$
  > Cluster $e/\gamma$ (typical shape)

> **Tau candidate**
  > Matching of hadrons and $e/\gamma$ in a cone of $R = 3.0/p_T$
  > Apply mass cuts
Hadronic tau reconstruction

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- **Tau candidate reconstruction**
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  - Apply mass cuts

- Require **isolation** in a cone of $R = 0.5$ around the tau candidate

The isolation requirements define the working point of the algorithm
Background processes

Final states considered here

- one $\tau$ decays to $e$ or $\mu$ + neutrinos
- one $\tau$ decays to hadrons + neutrinos

The main backgrounds are

- Drell-Yan production ($\mu\mu$ or $ee$) where a lepton is mis-identified as a tau
- W+jets events where $W(\ell\nu)$ and the jet fakes a tau
- QCD events where one jet fakes a tau and another jet fakes a lepton
- Very small contributions from diboson and top production
Corrections to MC - Lepton scale factors

> Measure **efficiency** in data and simulation, for lepton identification criteria and triggers

Derive a correction to apply on simulation with Tag&Probe method

> **Selection**

Z(\(ee\)) and Z(\(\mu\mu\)) events (from data and Drell-Yan simulated sample)

> **Fit** the dilepton invariant mass distribution

Exponential bkg, asymmetric gaussian for the signal

**Efficiency** \( \epsilon = \frac{\#\text{passing}}{\#\text{total probes}} \) in [80-102] GeV

![Efficiency curves](images/efficiency.png)

**Efficiency curves** \( \epsilon (p_T) \) in different eta regions

Scale factors ~ 95%
Data and event selection

> Amount of collected “good” data in the 25 ns runs is ~ 2.2 fb⁻¹

> Trigger
- Muon with $p_T > 18$ GeV
- Electron with $p_T > 23$ GeV

> Selection
- Identification and isolation criteria for leptons
- Tau $p_T > 20$ GeV
- Prefer most isolated tau-lepton pair
- No additional leptons in the event

![CMS Integrated Luminosity, pp, 2015, $\sqrt{s} = 13$ TeV](image)
Kinematic distributions - $e\tau$ channel

Use of transverse mass of the electron+MET system to reject $W$+jets events

$$M_T(e, \text{MET}) = \sqrt{2p_T^e \text{MET} (1-\cos \Delta \phi)}$$
Kinematic distributions - $\mu\tau$ channel

Use of transverse mass of the muon+MET system to reject W+jets events

$$M_T(\mu, MET) = \sqrt{2p_T^{\mu} \cdot MET \cdot (1-\cos\Delta\phi)}$$
Visible mass distribution

Systematic uncertainties included so far

- background normalization (QCD:30%, VV:20%, W:15%, ttbar:10%, Z(ℓℓ):10%)
- luminosity (4.6%)
- tau ID (8%)
Cross section estimate

> Theoretical value \( \sigma^{\text{theo}}(Z \rightarrow \tau\tau) = 2008.4 \pm 75.7 \text{ pb} \)

> Measured cross section

Counting events in the mass region [40-90] GeV

\[
\sigma^{\text{meas}}(Z \rightarrow \tau\tau) = \frac{\text{Data} - \text{MC (bkg)}}{\text{MC (Z\rightarrow\tau\tau)}} \cdot \sigma^{\text{theo}}(Z \rightarrow \tau\tau)
\]

> from the \( e\tau \) channel

\( \sigma^{\text{meas}}(Z \rightarrow \tau\tau) = 2010 \pm 180 \text{ (lumi)} \pm 20 \text{ (stat)} \pm 350 \text{ (sys)} \text{ pb} \)

> from the \( \mu\tau \) channel

\( \sigma^{\text{meas}}(Z \rightarrow \tau\tau) = 1980 \pm 150 \text{ (lumi)} \pm 12 \text{ (stat)} \pm 260 \text{ (sys)} \text{ pb} \)
Summary

> I have presented the first look at $Z(\tau\tau)$ events with the 13 TeV data

> **Fairly good agreement** between data and simulation

  > After correcting for different pileup and lepton efficiencies wrt data

  > This is reflected in the good agreement in the $Z(\tau\tau)$ cross section estimate

> Currently working on improving estimate of the most difficult **backgrounds** and fake rates and evaluating **systematic uncertainties**

> This is an important step for **commissioning** the Higgs to $\tau\tau$ search

> Working for having public $H(\tau\tau)$ results with the 13 TeV data

> Looking forward for **more data** to come!
Thanks for your attention!

Are there any questions?
Valeria Botta
PhD Student
DESY Hamburg
valeria.botta@desy.de

BACKUP

DPG Spring Meeting
Hamburg, 29.02.2016
Evidence for Higgs to fermions decays

CMS Collaboration, Evidence for the direct decay of the 125 GeV Higgs boson to fermions, Nature Phys. 10 (2014)
Tag & Probe Selection

**Muons**

- **Trigger**
  - HLT_{IsoMu20}

- **Tag Muon**
  - passes baseline Id/Iso selection
  - matched to the respective HLT filter

- **Probe Muons**
  - $p_T > 10$ GeV, $|\eta| < 2.4$
  - loose cut on IPs $|dxy| < 2$ mm, $|dz| < 5$ mm

- **Tag & Probe pair:** opposite sign, well separated ($\Delta R > 0.5$), $m_{\ell\ell} > 50$ GeV
  - If the probe lepton satisfies the tag selection, the pair is considered twice

**Electrons**

- **Trigger**
  - Data: HLT_{Ele23} WPLoose_Gsf
  - MC: HLT_{Ele22}_eta2p1_WP75_Gsf + online $p_T > 23$ GeV

- **Tag Electron**
  - passes baseline Id/Iso selection
  - matched to the respective HLT filter

- **Probe Electrons**
  - $p_T > 13$ GeV, $|\eta| < 2.5$
  - loose cut on IPs $|dxy| < 2$ mm, $|dz| < 5$ mm
Muon Identification efficiencies

Private Work

Muon Identification efficiencies

Private Work

Private Work

Valeria Botta  |  Study of Z boson events in the decay to a tau lepton pair in the semileptonic channels with the CMS experiment at 13 TeV  |  29.02.2016
Electron Identification efficiencies

> Scale factors between 92 and 98 %
Single lepton trigger efficiencies

Triggers to collect the T&P samples (must be matched by the tag lepton)

**Muons** : HLT\_IsoMu20

**Electrons** : HLT\_Ele23\_WPLoose\_Gsf in data and HLT\_Ele22\_eta2p1\_WP75\_Gsf + online $p_T > 23$ GeV in MC

Trigger efficiency is measured relative to the offline selection

Tag lepton must match the T&P triggers (above) and pass offline selection

Probes are all leptons passing Id\&Iso cut

Passing probes: leptons matching trigger objects (from the trigger we want to study, i.e. IsoMu18 and Ele23)
Trigger efficiencies

Valeria Botta  |  Study of Z boson events in the decay to a tau lepton pair in the semileptonic channels with the CMS experiment at 13 TeV  |  29.02.2016
Validation of the electron scale factors on $Z(\text{ee})$ events

No scale factors applied

Scale factors applied
Validation of the electron scale factors on Z(\(\mu\mu\)) events

No scale factors

![Histogram of events vs. trailing muon p_T with no scale factors](image1)

Scale factors

![Histogram of events vs. trailing muon p_T with scale factors](image2)
Corrections to MC - Pile up reweighting

> Different number of pile up interactions in simulation and in data

\( <\text{PU}> \sim 11.5 \) in data and \( <\text{PU}> \sim 16 \) in simulation

> Derive the pile up distribution in data

\#PU = \text{instantaneous luminosity} \times \sigma(\text{min bias})

Compute instantaneous luminosity for each active bunch and take the weighted average according to the recorded luminosity per bunch

> Get the pile up distribution in simulated samples

> Assign a \textbf{weight} to each simulated event
The dimension of the strip is allowed to vary depending on the $p_T$ of the $e/\gamma$ to be merged.

Low $p_T$ electrons belonging to the tau decay can fall outside the fixed strip window and spoil the isolation of the tau candidate.
Isolation is computed considering charged particles not assigned to the tau candidate, coming from the PV, in the isolation cone

\[ I_T = \sum p_T^{\text{charged}} (d_Z < 0.2 \text{ cm}) + \max (0, \sum p_T^{\gamma} - \Delta \beta) \]

The beta factor corrects on a statistical basis for energy deposit due to pile up
Backup - Anti-electron discriminator

- Expected efficiency and fake rate
Kinematic distributions - Eta